Unit I: The Physics of Everyday Things

A. Introduction to Physics

The Nature of Science

The scientific worldview:

- The world is understandable; we assume the basic rules are the same everywhere.
- Scientific ideas are subject to change; new observations can challenge theories.
- Scientific knowledge is durable; modification of ideas, not outright rejection, is the norm.
- Science cannot provide complete answers to all questions; some things cannot be proved or disproved by their very nature.

Scientific inquiry:

- Science demands evidence.
- Science is a blend of logic and imagination; scientists do not work only with data and well developed theories. Inventing hypotheses or theories to imagine how the world works and then figuring out how they can be put to the test of reality is as creative as writing poetry, composing music, or designing skyscrapers.
- Science explains and predicts.
- Science is not authoritarian; nobody has special access to the truth.
- There are generally accepted ethical principles in the conduct of science.

Physics is the study of the world around us. More so, it is the study of matter and energy and how they interact. We attempt to explain the world through simple rules and mathematics.

Measurement and Analysis

Scientific Notation

Scientific notation is a quicker way of writing very large or very small number.

Rules for writing in scientific notation:

1. Write down all the significant numbers
2. Put a decimal after the first number. (the number will now be between 1-10)
3. Write “x 10”
4. Write the power corresponding to the number of places the decimal was (would have) been moved. (Moving right is negative, moving left is positive)
    - Count the number of digits between where the decimal was before and where it is now

Ex. Write 25000000000000 in scientific notation.

Ex. Write 0.0000000000300 in scientific notation.

Ex. Write 3.256×10^{5} in decimal notation.

Ex. Write 7.20×10^{-7} in decimal notation.

Arithmetic Operations with Scientific Notation

Look for and learn to use the EXP button on your calculator.

Units

Units identify what a specific number represents. For example, the number 42 can be used to represent 42 miles, 42 kilometers, 42 pounds, or 42 elephants. Without the units attached, the number is meaningless. The information is incomplete.

While there are many units systems, we use the SI units (Système International d'Unités).

The metric system (our version of SI) is designed to keep numbers small by converting to similar units by factors of 10.

Prefixes are added in front of a base unit to describe how many factors of 10 the unit has changed.

Base units of measurement are generally described by one letter:

- m – meter (length)
- s – second (time)
- g – gram (mass) *The base unit for mass is actually the kg (kilogram)
- L – litre (volume)

Derived units are combinations of base units. For example, speed is measured in m/s.

Metric Prefixes

See handout of prefixes.

Converting Units

Step Method:

Move the decimal the same number of distance between the two prefixes on the prefix chart.

Ex. Convert 45 Gm to km.

Ex. Convert 15 nm to km.

Ex. Convert 120 cm to nm.

Ex. Convert 23 km to cm.

Multiply by One:

- Multiply the measurement by a fraction that equals 1
- The fraction will contain the old unit and the new unit.
- The fraction must cancel out the old unit. (follow the rule that tops and bottoms cancel out)

Ex. Convert 24mm into m.

Ex. Convert 15.0 m/s into km/h.

The Sanity Test

After any calculation or problem, stop, take a deep breath, and look at your answer. Does your answer make sense?

Imagine you are calculating the number of people in a classroom. If the answer you got was 1 000 000 people, you would know it was wrong – that's an insane number of people to have in a classroom. That's all a sanity check is: is your answer insane or not?

In using the sanity test, it helps to know typical values of things.

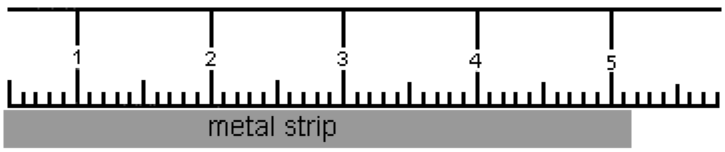
Accuracy vs. Precision

Accuracy is to the extent that a measurement agrees or compares with an accepted value or standard. A very accurate measure of boiling water might be 99.8°C, because it would be compared to the standard of 100°C.

The difference between an observed or measured value and a standard is known as error, and is sometimes written as a percentage.

The accuracy of a measuring instrument depends on how well it compares to an accepted standard, and it should be checked regularly. A known 500.0 g mass should show that same reading on a balance. If it doesn't, the balance should be re-calibrated.

If you were measuring a piece of metal with a ruler (like below), you would get a more exact measurement by using the side graduated in mm (the bottom of the ruler).

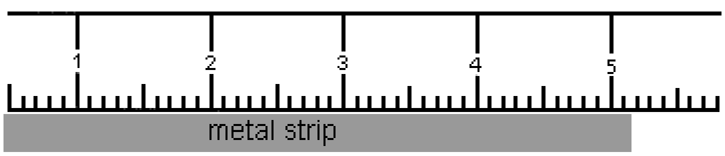


Precision is the degree of exactness that measurement can be reproduced. The precision of a measuring tool is limited by the graduations or divisions on its scale. In other words, you will have a more precise measurement of the metal strip above by using the graduations on the bottom of the ruler (mm) rather than the top (cm).

The precision of an instrument is indicated by the number of decimal places used. For example, 5.14 cm is more precise than 5.1 cm.

Significant Figures

When measuring, the precision is limited by the device - - the number of digits is also limited. Valid digits are called significant digits or significant figures. Significant digits consist of all digits known with a certainty plus the first digit that is uncertain.



The strip above is somewhere between 5.1 and 5.2 cm. We would state that the length is 5.14 cm. The last digit is an estimate (uncertain), but it is still valid and considered to be significant. There are 3 significant digits in this measurement; the 5 and 1 are known and the 4 is an estimate.

If the strip was dead on the 5.1 graduation, we should record this as 5.10 cm and we would have 3 significant digits.

Rules for Significant Figures

All non-zero digits in a measurement are considered significant. It's the zeros that sometime create problems.

1. Non-zero digits are always significant.
127.34 grams = 5 significant digits (s.d.)

2. All zeros between nonzero digits are significant.
1205 m = 4 s.d.

3. All final zeros to the right of a decimal point are significant.
21.50 grams = 4 s.d.

4. Zeros used only for spacing the decimal are not significant.
0.0025 = 2 s.d.

5. Zeros to the right of a whole number are ambiguous. A bar placed over a zero makes all numbers up to and including the barred zero, significant.

$50\overline{0}$ =3 s.d.

Sometimes, it is just assumed that all trailing zeroes are significant.

All digits written in scientific notation are significant.

Operations with Significant Digits

Adding and Subtracting:

The final answer cannot be more precise than the least precise measurement. In other words, the answer must have as few decimal places as the number with the fewest decimal places being added or subtracted.

Ex:

3.414 s + 10.02 s + 58.325 s + 0.000 98 s	1884 kg + 0.94 kg + 1.0 kg + 9.778 kg
2104.1 m - 463.09 ms	2.326 hr - 0.104 08 hr

Multiplying and Dividing:

Look at the number with the least amount of significant digits. Round the final answer to contain this many significant digits.

Ex.

10.19 cm × 0.013 cm	140.01 cm × 26.042 cm
80.23 m ÷ 2.4 s	4.301 kg ÷ 1.9 cm^3

Multiple Operations:

When a series of calculations is performed, each interim value should not be rounded before carrying out the next calculation. The final answer should then be rounded to the same number of significant digits as contained in the quantity in *the original data* with the lowest number of significant digits.

For example, in calculating (1.23)(4.321) ÷ (3.45 – 3.21), three steps are required:

3.45 – 3.21 = 0.24

(1.123)(4.321) = 5.21483

5.31483 ÷ 0.24 = 22.145125

The answer should be rounded to 22.1 since 3 is the lowest number of significant digits in the original data. The interim values are not used in determining the number of significant digits in the final answer.

Graphing

See handout

Manipulating Equations

Since mathematics is a language of physics, it is important that you be able to rearrange formulas so that they are in a workable format. Basic algebra applies.

Sources

The Nature of Science
http://www.project2061.org/publications/sfaa/online/chap1.htm?txtFsfaaol%2Fchap1%2Ehtm

The Free High School Science Texts: A Textbook for High School Students Studying Physics.
http://upload.wikimedia.org/wikimedia/en-labs/a/ab/Fhsstphysics.pdf

Physics 20 Resources
http://www.saskschools.ca/~phys20de/index.htm

Pearson Alberta Physics Source
http://www.physicssource.ca/index2.html

Unit Two: Waves

A medium is the material that a wave travels through.

A wave can be described as the transfer of energy in the form of a disturbance, often through a medium such as water. It is a travelling oscillator that carries energy from place to place. When a wave travels through a medium, the medium is only temporarily disturbed. When an ocean wave travels from one side of the Mediterranean Sea to the other, no actual water molecules move this distance. Only the disturbance propagates (moves) through the medium.

Types of Waves

Electromagnetic Waves

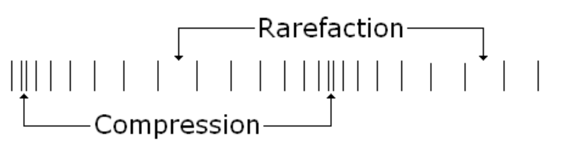
Electromagnetic waves are disturbances that are made up of electrical and magnetic fields. These waves do not require a medium. They travel through space at approximately 3.00×10^8 m/s. Light, x-rays, and radio waves are all examples of electromagnetic waves.

Mechanical Waves

Mechanical waves are disturbances that require a medium to travel through. A slinky, water, and sound are all examples of mechanical waves. There are two main types of mechanical waves – longitudinal and transverse.

Longitudinal Waves

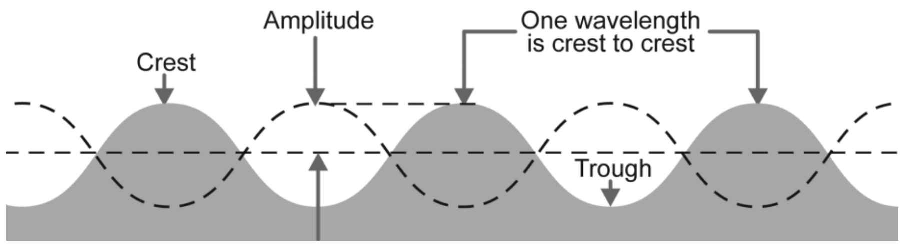
A longitudinal wave causes the particles of a medium to move parallel to the direction of a wave. Sound waves are example of this.



Rarefactions are regions where the particles are farthest apart. Compressions are where the particles are closest together.

Transverse Waves

Transverse waves cause the particles of the medium to vibrate perpendicularly to the direction of motion of the wave.



The uppermost part of the wave is a called a crest. The lowest part is called a trough. The amplitude is the maximum displacement from the rest or equilibrium position. It is a measure of the energy in the wave.

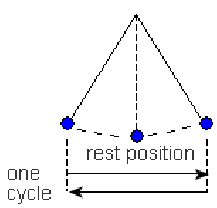
The shortest distance between points where the wave pattern repeats is called the wavelength. The greek letter λ, lambda, represents wavelength. There is one wavelength between crests and one wavelength between troughs.

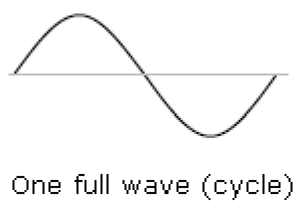
Ex. Sketch a wave with a wavelength 12 m and an amplitude of 2 m.

Periodic Motion

Any motion that repeats itself in regular intervals is called periodic motion. Examples are pendulums on clocks, pistons in a car engine, and your lungs as you breathe. The displacement of a particle during periodic motion is called harmonic motion. The pendulum bob on the clock's pendulum and vibrating guitar strings are good examples of this.

One complete vibrations, or oscillation, is called a cycle. In a pendulum, one cycle is going there and back. In a water wave, it is going up, back down, and returning to the starting level.





A single wave or movement is called a pulse. Regular or repeated waves are called periodic waves.

Period and Frequency

Period (T) = The time required to complete one full cycle

= time / # of cycles

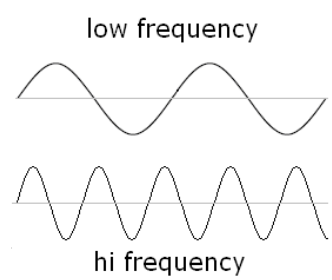
$$T = \frac{t}{cycles}$$

Frequency (f) = The number of cycles or oscillations in 1 second

= # of cycles / time

$$f = \frac{cycles}{t}$$

$$f = \frac{1}{T}$$



From this, we can see that T and f are reciprocal of one another. Therefore:

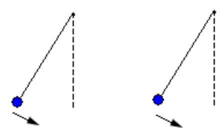
$$T = \frac{1}{f}$$

The unit used to measure frequency is the hertz (Hz), name after Heinrich Hertz. One cycle per second is one hertz.

Phase

In Phase

The diagram below shows pendulums moving in the same direction. They are said to be in phase.



Out of Phase

The diagram below shows one pendulum moving right while the other moves left. They are said to be out of phase.

Ex. How do the windshield wipers on a car move?

Ex. At a Justin Bieber concert, the crowd waves their hands back and forth with a period of 3 seconds. What is the frequency?

Ex. Determine the period of a guitar string that completes 25 cycles in 5 seconds.

Ex. What is the frequency of the guitar string above?

Wave Equation

The speed of a wave is related to its wavelength and frequency. This equation applies to all types of waves:

$$v = f\lambda$$

Where v = speed of wave
f = frequency
λ = wavelength

As period is the inverse of frequency, we could also have:

$$v = \frac{\lambda}{T}$$

Ex. A wave has a wave speed of 243 m/s and a wavelength of 3.27 cm. Calculate:

a. The frequency of the wave

b. The period of the wave

Ex. The wavelength of a water wave in a ripple tank is 0.080 m. If the frequency of the wave is 2.5 Hz, what is its speed?

Ex. The average wavelength of visible light produced by the sun is 500 nm (5.0×10^{-7} m). The frequency of these waves is 6.0×10^{14}Hz.

a. What is the velocity of the sun's light?

b. If the earth is 1.5×10^{11} m from sun, how long does light take to travel from the sun to the earth?

Wave Interference

Principle of Superposition

Two particles cannot be in the same place at the same time. Matter, after all, takes up space. This is not true for waves.

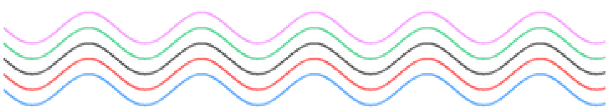
In mechanical waves, when two or more waves cross in a medium, the resultant wave is the sum of the two waves.

Phase difference: A constant phase difference occurs when 2 waves have the same frequency, and different initial phases.

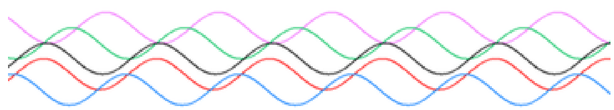
In phase (constructive interference): When two waves have zero phase difference. The resulting disturbance will be larger than the individual disturbances that caused it.

Out of phase (destructive interference): When there is not zero phase difference. The resulting disturbance will be smaller than the individual disturbances that caused it.

In-Phase Waves:

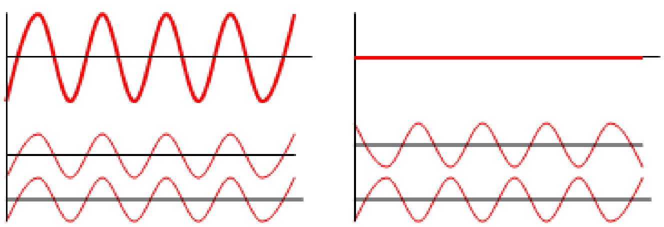


Out-of-Phase Waves:



In-Phase Waves:

180° Out of Phase:



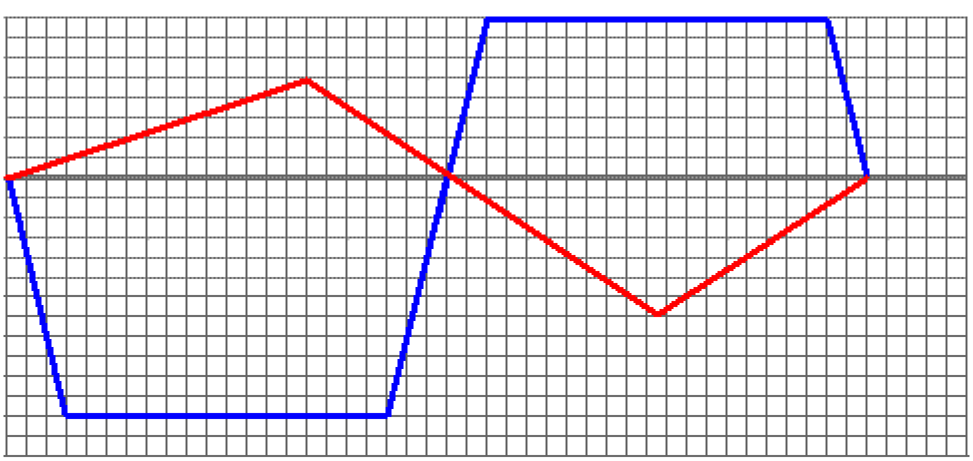
Resultant

Wave 1

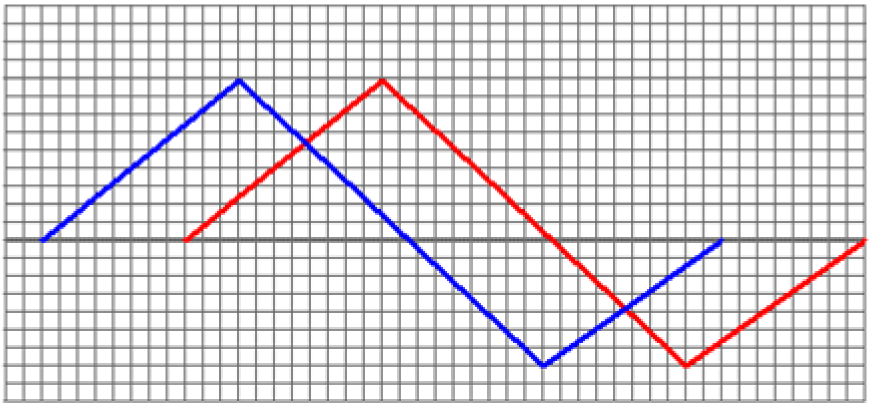
Wave 2

Whenever two or more waves pass through each other, the resulting disturbance at a given point in the medium may usually be found by adding the individual displacements that each wave would have caused.

Ex.



Ex.



Waves at Boundaries Between Media

The speed of a mechanical wave does not depend on the amplitude or the frequency of the wave. It depends only on the properties of the medium. Often, a wave moves from one medium to another.

When a wave travels across a medium it may encounter an obstacle or another medium through which it could travel. The wave can be reflected, such as sound waves reflecting off a canyon to produce an echo, or transmitted, such as sound waves transmitting from water to air to allow you to hear a sound from under water.

When a wave encounters a new medium, part of the energy is transmitted to the new medium, and some of the energy is reflected back. Here is what happens in general:

If the new medium is less dense than the first medium:

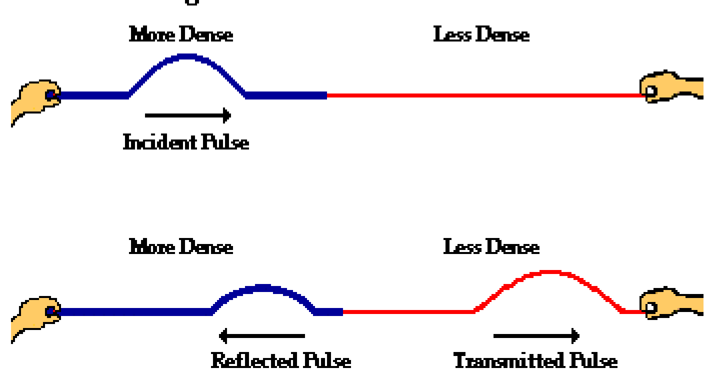
For the transmitted wave:

- Amplitude increases
- Speed increases
- Wavelength increases
- Frequency remains the same

For the reflected wave:

- Amplitude decreases
- Speed remains constant
- Wavelength remains constant
- Frequency remains the same

A wave traveling from a more dense to a less dense medium…



…will be reflected off the boundary and transmitted across the boundary into the new medium. There is no inversion.

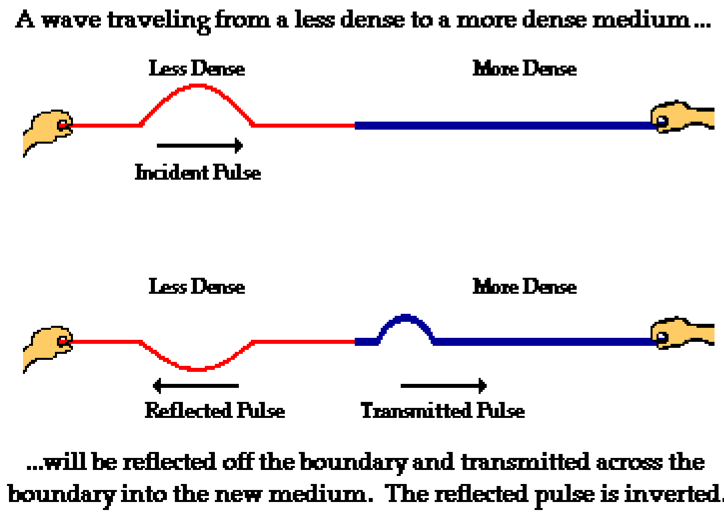
If the new medium is more dense than the first medium:

For the transmitted wave:

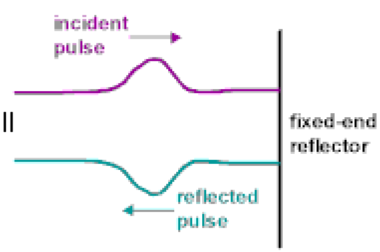
- Speed decreases
- Wavelength decreases
- Frequency remains the same

For the reflected wave:

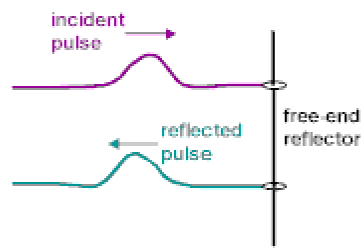
- Amplitude decreases
- Speed remains constant
- Wavelength remains constant
- Frequency remains the same



For a fixed-end, the pulse hits the obstacle that is considered to be infinitely heavy. Therefore, no amplitude is transmitted. The reflected pulse in this case will be inverted.

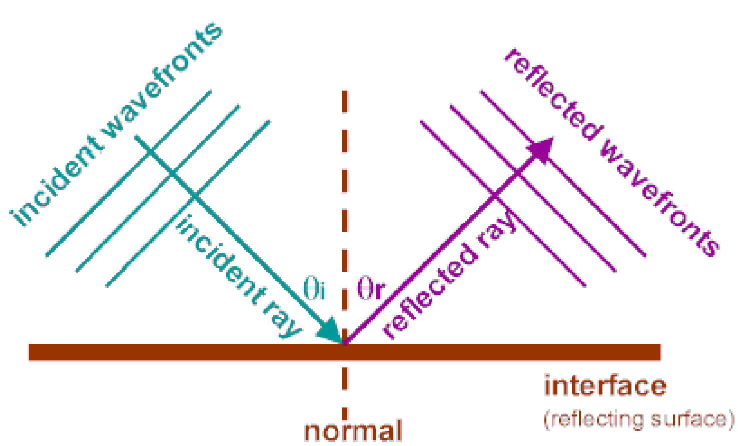


For a free-end, the pulse hits an obstacle that is considered to be infinitely light. When the wave hits this free-end it is reflected upright, as though no obstacle had been encountered.

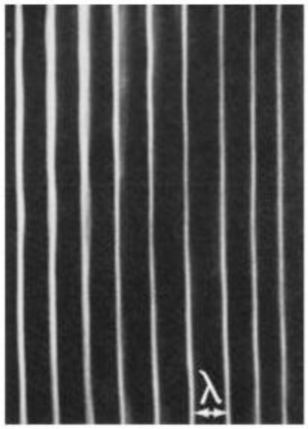


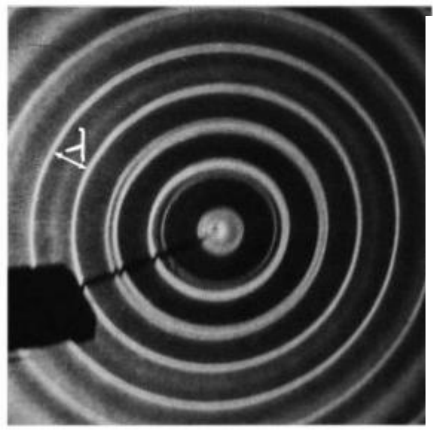
Reflection of Waves

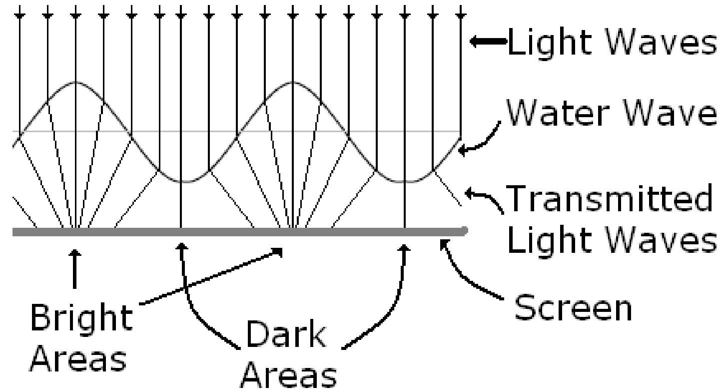
Waves often move in two or more dimensions. Directions of these waves are shown with ray diagrams. A ray is a line drawn at a right angle to the crest of a wave. It shows the direction of the wave and not the actual wave itself. The direction of the barrier is also shown by a line drawn at a right angle to it. This line is called the normal. The angle between the incident ray and the normal is called the angle of incidence. The angle between the normal and the reflected ray is called the angle of reflection. The law of reflection states that the angle of incidence is equal to the angle of reflection.

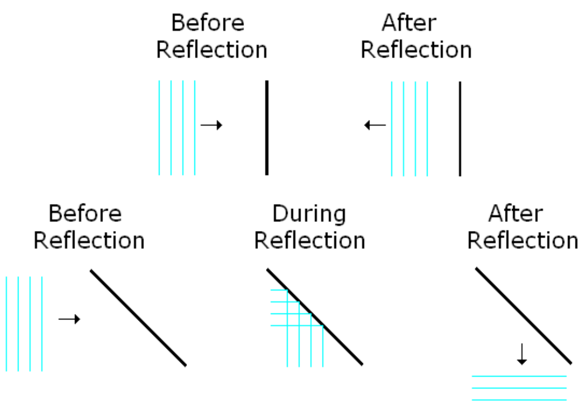


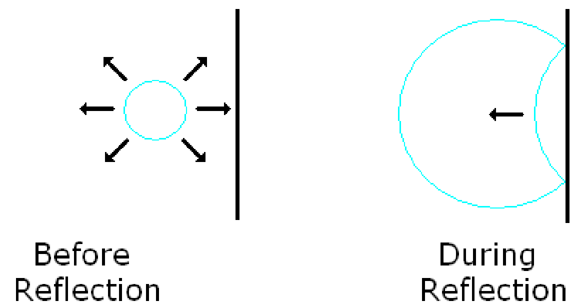
Waves in Two Dimensions



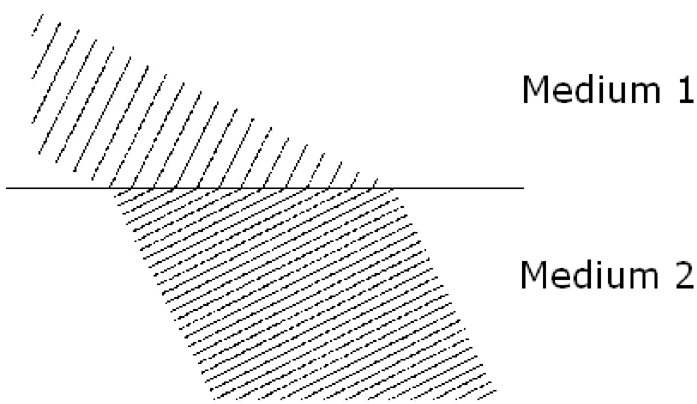








Recall that when a wave enters a new medium, its wavelength changes while its frequency remains the same.



Refraction

In the first media we can say:

$v_1 = f\lambda_1$	(1)

Or rearrange this as:

$f = \frac{v_1}{\lambda_1}$	(2)

When the wave enters the second media, the velocities and wavelengths change, so we can alter (2) to say:

$$f = \frac{v_2}{\lambda_2} \qquad (3)$$

Is there a change in frequency from one media to the next?

Since the frequencies in (2) and (3) are equivalent we can combine equations (2) and (3) to say:

$$\frac{v_1}{\lambda_1} = \frac{v_2}{\lambda_2} \qquad (4)$$

Or,

$$\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} \qquad (5)$$

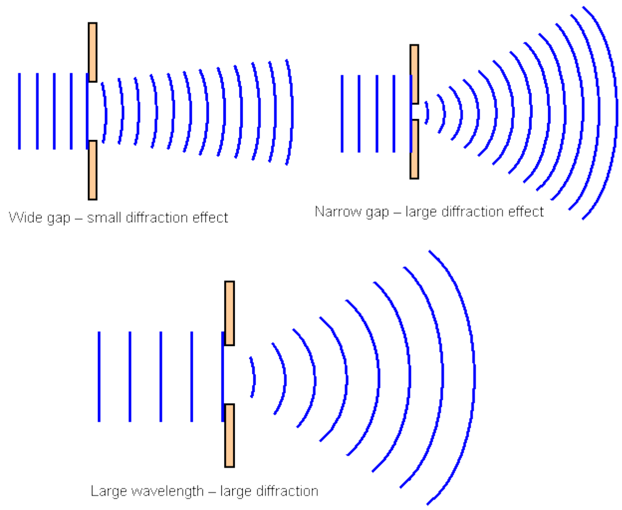
Equation (5) will help us to relate velocities and wavelengths between different media.

Ex. The speed of a sound in air is 344 m/s and has a wavelength of 1.37 m. Determine the speed of sound in water if the wavelength is 5.90 m.

Ex. During your slinky experiment you tied a large coiled slinky to a small coiled slinky. After sending a pulse you notice that the wavelength on the large coil side is 1.5 m and you determine the velocity to be 3.5 m/s. If the velocity on the small coil slinky is 3.0 m/s, what is the wavelength?

Diffraction of Waves

When waves encounter a small hole in a barrier, they do not pass straight through. Instead, they bend around the edges of the barrier, forming circular waves that spread out. This spreading around the edge of a barrier is called diffraction. Waves with long wavelengths are diffracted more than waves with short wavelengths. When a wave passes through a slit, the diffraction is maximized when the wavelength is about the same as the slit width.



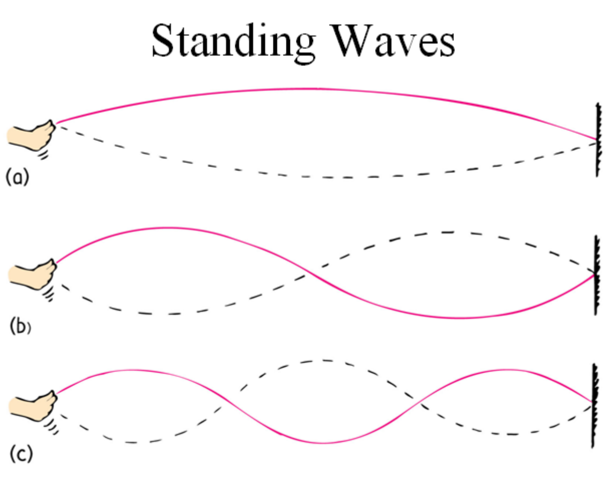
Interference

See Handout.

Standing Waves

Standing waves occur when a string or spring vibrates, like on a guitar, causing a wave travel down one end of the string, reflect off the end of the instrument and travel back down the string in the opposite direction. At certain points along the string the wave traveling in one direction is always out of phase with the wave traveling in the other direction. This leads to destructive interference all the time and the string does not move. These points are called nodes. Nodes are separated by ½ λ. The fixed end in a standing wave pattern in one-dimension is a nodal point

At certain points along the string the wave traveling in one direction is always in phase with the wave traveling in the other direction. This leads to constructive interference and the string has maximum amplitude. These points are called antinodes. Antinodes are separated by ½ λ. Antinodes are separated from nodes by ¼ λ.



For a standing wave to occur:

- the two waves must have a fixed frequency
- there must be a whole number of half wavelengths in the entire pattern

Since the fixed ends are nodal points, only certain frequencies will produce a standing wave pattern. These are the resonant frequencies for that medium.

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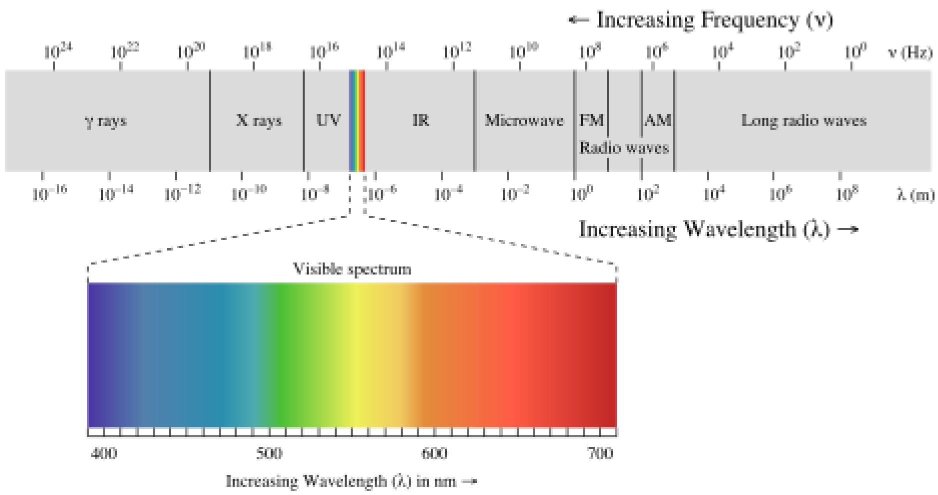
Unit III - Reflection of Light

Introduction to Light

The **electromagnetic spectrum** is the range of wavelengths that light can exist in.

An electromagnetic wave is simply a light wave. However, we reserve the term **light** for the part of the spectrum we can see. This is called the **visible** part of the spectrum. Other parts of the spectrum have different names. It is important to note that each type of wave is a light wave, but just has a different wavelength, energy, and behaviours/purposes.



A **luminous body** is an object that emits light.
Ex.

A **nonluminous body** does not emit light, but reflects, or absorbs it. These are often referred to as **illuminated bodies**.
Ex.

An **incandescent body** is an object that emits light when it is heated. The type, or color, of light it emits depends on its temperature.
Ex.

Light naturally travels in straight lines. This is called **rectilinear propagation**. The only time that light does not travel in a straight line is when it passes through a strong gravitational field.

A **transparent** object transmits light, while it absorbs or reflects some as well.
Ex.

A **translucent** object only scatters and transmits light, but does not allow objects to be clearly seen through them.
Ex.

An **opaque** object is neither translucent nor transparent. These objects either absorb or reflect specific wavelengths of light. Most objects are opaque.
Ex.

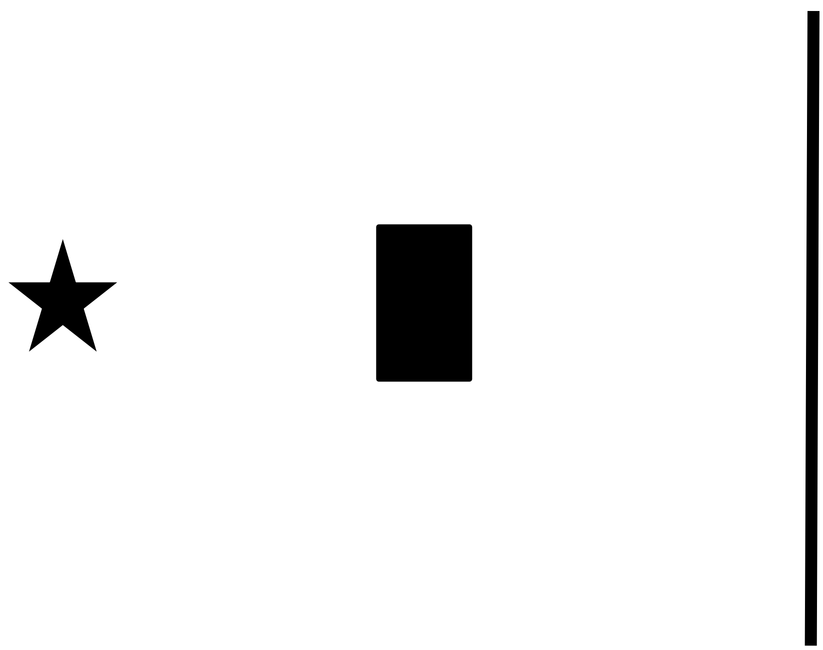
We can represent the path followed by light on paper by drawing **rays**. Rays do not actually exist in nature, but they are geometric constructs that help describe the nature of light.

A **beam** is thought of as a collection of rays.

Shadows form when an opaque object is placed in the path of light. We call a total shadow an **umbra**. We call a partial shadow a **penumbra**.

A total solar eclipse is observed from the **umbra** of the moon.

Ex. Draw the shadow(s) cast by the opaque object below in front of the light source. Label the shadow(s) as umbra or penumbra.



The Law of Reflection and Plane Mirrors

The law of reflection: the angle of reflection is equal to the angle of incidence.

Regular reflection (which occurs in mirrors) is when all the rays in a beam of light are reflected at the same angle.
Ex.

Diffuse reflection (which is much more common) occurs when the rays in a beam of light are scattered off a surface.
Ex.

Describing Images

A plane mirror is a flat mirror.

The images formed in a plane mirror appear to be behind the mirror. This means that the light **appears** to be coming from behind the mirror. We call images formed in this fashion **virtual images**. A virtual image is an image that light does **not** pass through, but only **appears** to pass through.

We describe images with four characteristics:

1) Magnification - is the image smaller or larger than the object?

2) Orientation - is the image upside down or right side up compared to the object?

3) Type - is the image real or virtual? (we will discuss real images later).

4) Position - is the image closer, further, or the same distance from the mirror as the object?

We locate objects using ray diagrams, which are close approximation to numerical solutions. We will later do the math to get theoretical solutions.

When drawing rays, we must always draw a normal so we can measure the angle of incidence or reflection, and arrows to show which way the rays are traveling.

Recall that the angle of incidence is the angle between the **normal** and the incident ray, **not the mirror!**

Likewise, the angle of reflection is the angle between the **normal** and the reflected ray, **not the mirror!**
Ex.

Locating and Seeing Images

To locate images in a plane mirror we simply need to measure the object's **perpendicular distance** from the mirror. The image will be the same **perpendicular distance** away from the mirror (but behind it).

It is very important to realize that for an eye to see something, light must travel directly from the 'something'. So, if an eye is to see an **image** then light must be travelling directly from (or appear to be coming directly from) the image.

To draw the light rays from an image, we must first draw a straight line from the image to the eye. This ray will turn out to be the **reflected ray**.

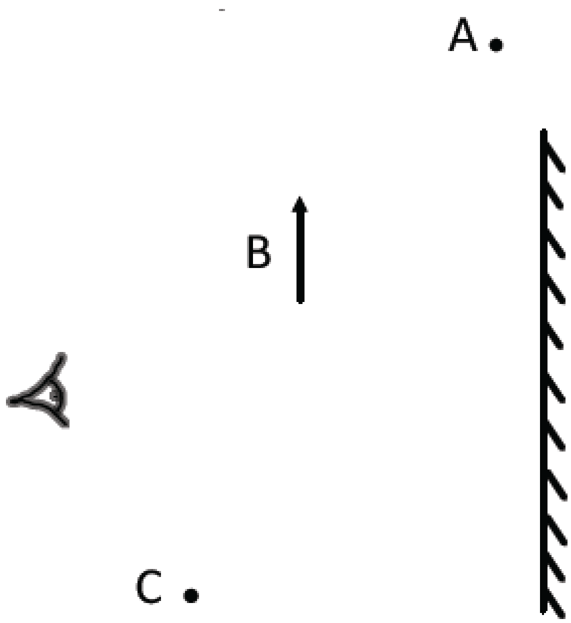
If this straight line does not go through the mirror than the eye cannot see the image!

All lines on the backside of a mirror must be dashed because they don't **actually** exist, they just appear to exist. All lines on the front side of the mirror must be solid because that light came from something real.

Once your first line is drawn you must decide where the reflected ray came from. In other words, you must find the **incident ray**. The incident ray will always come from the same part of the object that the reflected ray came from.

Finally, arrows must be shown.

Ex. Locate the images of the objects below in the mirror. Draw the rays to determine if the eye can see the images.



Curved Mirrors

Although we mostly associate mirrors with plane mirrors, curved mirrors are very useful. Even though their surfaces are curved, curved mirrors still are governed by the law of reflection.

That is, a curved mirror can be thought of several tiny plane mirrors put together at slightly different angles.
Ex.

There are two types of curved mirrors we will focus on.

1) **Concave mirrors**: If we imagined a sphere with a shiny inside, and we took a section of this sphere we would have a concave mirror. These are also called **converging** mirrors.

2) **Convex mirrors**: These mirrors are thought of a section of a sphere with a shiny outside. These are also called **diverging** mirrors.

Where have you seen curved mirrors used before?

Concave Mirrors

Definitions:

Vertex (V)- the geometrical center of a curved mirror.

Center of Curvature (C) - the geometrical center of the sphere the mirror is made from.

Principal Axis - a line that passes through the center of curvature and the vertex.

Radius of Curvature (R) - the distance from the center of curvature to the vertex.

Focal Point (F)- a point on the principal axis half way between the center of curvature and the vertex. This is a real point on a concave mirror, and a virtual point on a convex mirror.

Focal Length (f)- distance between focal point and the vertex. note: $R = 2f$

The Principal Rays

There are three rays we will use to locate images in curved mirrors. These are called principal rays.

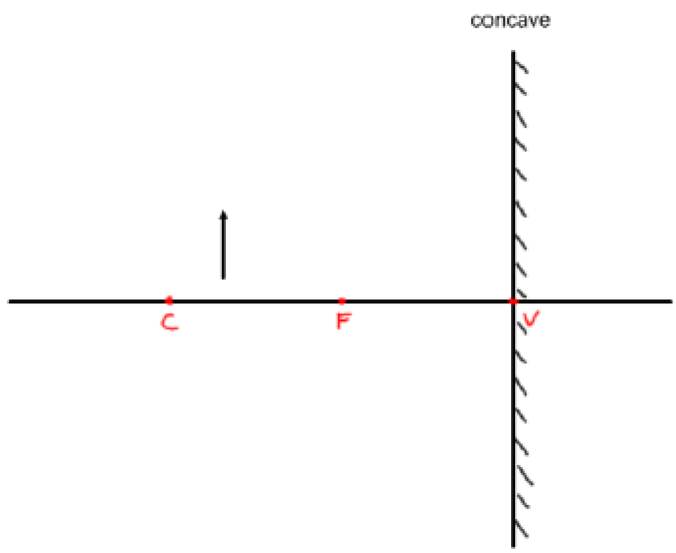
1) A ray travelling parallel to the principal axis will reflect through the focal point.

2) A ray travelling through the focal point will reflect parallel to the principal axis.

3) A ray that appears to travel through, or come from the center of curvature, will be reflected back in the direction it came from.

To locate an image, we need only 2 of the principal rays. However, if you draw accurately, all 3 rays should pass through the same point on an image.

Ex. Locate the following image in the concave mirror:

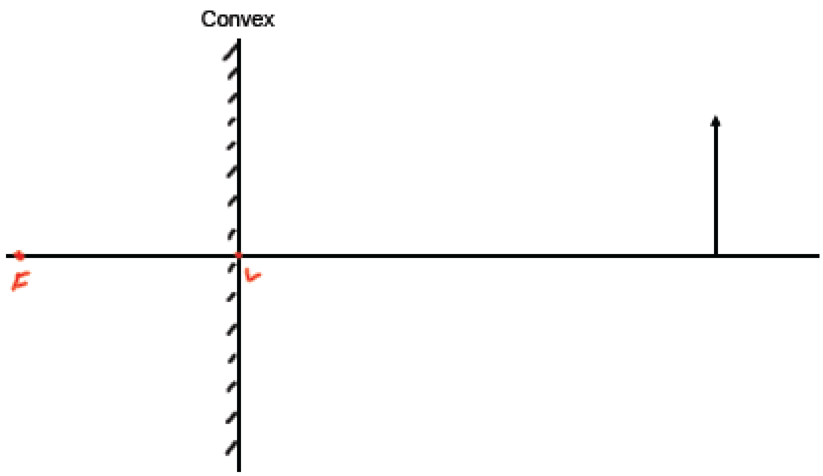


Convex Mirrors

To locate images in convex mirrors we can still use the same 3 principle rays. However, they look a bit differently in this type of mirror.

For a convex mirror, the focal point is behind the mirror, so this is a virtual point. If the focal point is virtual, then light actually does not go through it, light just appears as if it does.

Furthermore, for a convex mirror, all the images will be upright, virtual, and smaller than the object. The images will also appear between the focal point and the vertex.
Ex) Locate the image of the following object in the mirror below.



Scale Diagrams

We now know that locating images for objects that are about 2-3 cm in height is easy to do on paper. However, this is not very practical. For example, how are we supposed to locate the image of a person in a curved mirror if our paper is too small?

The answer is in scale diagrams!

A scale diagram is when you take measurements that are normally too big to fit on paper and shrink them down to a manageable size. Once the numbers are more manageable, we can draw ray diagrams to locate the images of large objects, and then use our scale to find out how big they would be in real life.

We are going to start defining a few measurements to make our lives easier from this point on:

The **distance of the object (d_o)** is the distance between the object and the mirror. We say that this is **always** a positive number as it is measured in front of the mirror.

The **distance of the image (d_i)** is the distance between the image and the mirror. If the image is **real** this will be a positive number. If the image is **virtual** (behind the mirror) this will be a negative number.

The **height of the object** is denoted **h_o**. This will be a positive number since our objects are always right side up.

The **height of the image** is denoted **h_i**. If the image is real, then the image is inverted; therefore, h_i will be negative. If the image is virtual, then the image is right side up; therefore hi will be positive.

Here is a chart to summarize the sign conventions discussed:

Measurement	Type of Image	
	Real	Virtual
d_i		
h_i		

One of the trickiest parts of scale diagrams is expressing the measurements back in the original scale. To do this, we can use proportions.

A handy proportion is $\frac{real\ life\ measurement}{scale\ measurement}$.

Ex. A diagram drawn to scale shows the distance of an image from a mirror is 2.50 cm. If the scale of the ray diagram is 1 m = 1 cm, how many meters is the image actually from the mirror?

Ex. A diagram drawn to scale shows the height of an image is 3.30 cm. If the scale of the ray diagram is 3 m = 2 cm, how tall is the actual image?

The scale you are drawing your diagram to must always be stated somewhere. This is usually done in the top left hand corner so that it is seen first.

Ex. A 2.00 m tall man is standing 5.00 m from a concave mirror with a focal length of 3.00 m. What is the distance of the image and the height of the image?

Ex. A 15.0 m tall object is sitting 20.0 m from a convex mirror with a radius of curvature of 30.0 m. What is the distance and height of the image?

Curved Mirror Mathematics

Now that we know how to locate images visually, let's see how we can locate and describe images mathematically. We will use two equations to describe images mathematically. The first equation is known as the **mirror equation**.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

where:

f = focal length
do = distance of the object
di = distance of the image

Recall that sometimes the distance or height of our image is positive, but sometimes it is negative. You may need to refer to the chart below for mirror math questions:

	Positive	Negative
d_o		
h_o		
d_i		
h_i		
f		

Ex. A 3.0 cm tall object is 6.0 cm from a concave mirror. If the image produced is 5.0 cm from the mirror, what is the focal length?

We can also describe the size of the image by calculating its magnification (M). The following equations are known as the **magnification relationships**:

$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Ex. A 2.7 m tall object produces a real image 1.1 m tall. What is the magnification?

Ex. An object produces a virtual image 2.5 m away from a concave mirror. If the focal length is 3.0 m, what is the distance of the object from the mirror?

Many questions need a combination of the mirror equation and one of the magnification relationships if there are too many unknowns.

Ex. A 2.0 m tall object 1.6 m in front of a convex mirror produces an image 0.625 m tall. What is the focal length of the mirror?

Unit IV: The Refraction of Light

Fast. It's Fast.

For ages, light was thought to travel instantaneously from one place to the next. There were a few attempts to measure the speed of light however:

Take one:
Galileo, in the 17th century, was the first person to try to measure the speed of light. He and his assistant stood on hilltops one mile apart with lanterns. Galileo would flash his light at his assistant, who opened a shutter on his lantern as soon as he saw Galileo's light.

Galileo timed how long it took to see his assistant's light. However, he found that the time of the event was too small to measure.

Take two:
Ole Romer during the 1670's made careful observations of Jupiter's moon Io. Since Io has a very stable orbit, Romer concluded he should be able to predict where Io is in its orbit. However, he noticed that sometimes the moon was behind schedule and sometimes it was ahead, depending on the time of the year.

Romer discovered that Io was ahead of schedule when Earth was closest to Jupiter, and behind when they were farthest apart. This is due to the fact that light has to travel farther when Earth and Jupiter are far apart.

His calculations showed that light travelled at 300 000 000 m/s, or 3.00×10^8 m/s.

Although with better equipment we have measured the speed of light to be 299 792 456.2 m/s we still use Romer's 3.0×10^8 m/s as a good approximation. We will use the following equation when dealing with the speed of light:

$$c = \frac{d}{t} \qquad\qquad v = \frac{d}{t}$$

where:
c = the speed of light (3×10^8 m/s)
d = distance travelled (m)
t = time (s)

Therefore, if we know the distance we can solve for the time it takes light to travel that distance. Likewise, if we know the distance light travels we can find out how much time it takes to do so.

One thing to mention is that since time must be in seconds, we should brush up on conversions.

1 min = 60 s 1 hour = 60 min 1 day = 24 h 1 year = 365.25 days

Ex. How many seconds are in 2.35 years?

Ex. How long does it take light to travel from earth to a space ship that is 7.80×10^{10} km away?

Ex. A space ship orbiting a distant planet sends out a distress call via radio. How far is the receiving ship if they get the message 1.20 hours after it was sent?

Things are Far Away

Since astronomers deal with such vast distances, sometimes they use a distance called a **light year**. A light year is the **distance** light travels in 1 year. Note that it is **not** a measure of time!

What is the distance of a light year?

Another handy distance is an **astronomical unit (A.U.).** An astronomical unit is the distance between the sun and the earth.

What is the distance, in km, for 1 A.U. if it takes light 8.33 minutes to get from the sun to earth?

Another unit for distance is the **parsec**. We will not concern ourselves with its definition as it is beyond the span of this course. Just know:

1 pc = 3.26 ly

We will convert distances through dimensional analysis, just as we do with time conversions.
How many kilometers are in 1 parsec?

Ex. A star is 8.52 ly away. How many years does it take for light to reach us from this star? How many parsecs is this star away from earth?

Ex. How many seconds does light travel for if it travels a distance of 6.45 light years?

It Bends?

The substance light is travelling in is called a **medium**.

When light travels from one media to another it bends. This bending of light is known as **refraction.** The bending of light is due to the fact that light travels at different speeds in different media. Therefore, each substance has its own unique speed of light.

For example, light travels faster in air than in water.

The fastest light can travel is in a vacuum. This is basically 3.00×10^8 m/s. The next fastest is air, which we approximate at 3.00×10^8 m/s, although it **does** travel slower than in a vacuum.

Each medium has its own **index of refraction (n)**, which is a comparison of the speed of light in that particular substance, with the speed of light in a vacuum.

Note that there is a list of indices of refraction on the back of our formula sheet.

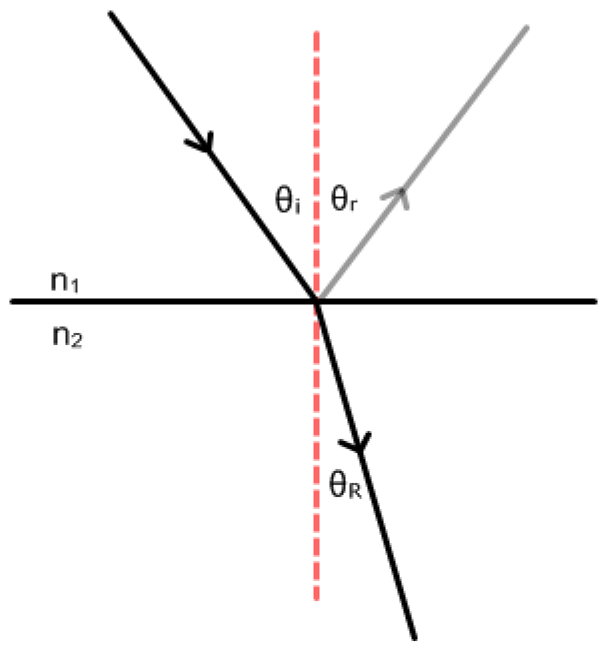
$$n = \frac{c}{v}$$

where:
n = index of refraction
c = speed of light in a vacuum (m/s)
v = speed of light in a medium (m/s)

Ex. What is the index of refraction of glass if the speed of light in glass is 2.00×10^8m/s?

Ex. Find the speed of light in water.

Ray diagram depicting refraction:



The point at which two media meet is called an **interface**.

When light hits an interface, it bends at the interface, but not in one material or the other. This happens at the **point of incidence**.

The line perpendicular to the interface running through the point of incidence is still called a **normal**.

The angle between the incident ray and the normal is the **angle of incidence**.

The refracted ray is the ray that leaves the interface through the second medium.

When an incident ray strikes an interface, most of the light will be refracted. The angle between the refracted ray and the normal is the **angle of refraction**.

Some of the light will get reflected. The angle between this reflected ray and the normal is still called the angle of reflection.

Spear Fishing:

Snell that? That's the Snell of Science.

There are two laws of refraction.

The first law of refraction is known as **Snell's Law** and is in the form of the following equation:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Where:
- n1 = incident substance
- θ1 = angle of incidence
- n2 = refractive substance
- θ2 = angle of refraction

The second law of refraction states that the incident and refracted rays are on opposite sides of the interface, and opposite sides of the normal.

We will use Snell's law extensively to study how light behaves at an interface.

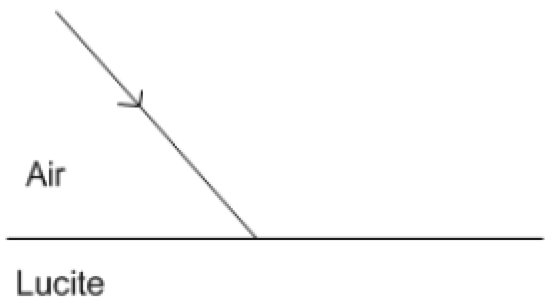
If light is travelling from less refractive medium (small n, fast speed of light) to a more refractive medium (big n, slow speed of light) the light will bend **towards** the normal.

If light is travelling from a more refractive medium to a less refractive medium then light will bend **away** from the normal.

Ex. An incident light ray is travelling in ice. It hits an ice-beryllium glass interface at 45.0°. What is the angle of refraction?

Ex. A cube of an unknown substance is submerged in water. If an incident ray travelling through the water strikes the unknown substance at 20.0° and produces an angle of refraction of 17.2°, what is the unknown substance?

Ex. Trace the light ray.



One phenomenon related to refraction is called **dispersion**. Dispersion is when a medium separates light into different colors on the spectrum.

This phenomenon is due to different wavelengths of light (or colors) having unique speeds in substances. Therefore, each color of light will bend at a slightly different angle, making them separate.

Total. Internal. Reflection.

The angle of refraction depends on two things: the substances involved, and the angle of incidence.

If the incident substance is more refractive than the second substance, then the ray will refract away from the normal. Therefore, as the angle of incidence increases, so does the angle of refraction.

If this is the case, then there should be an incident ray which will produce an angle of refraction of 90°.

The **critical angle** for two substances is an angle of incidence that produces an angle of refraction of 90°. This is always the same for two substances.

If the angle of incidence is **greater** than the critical angle, the ray will reflect. This is called total **internal reflection**.

Remember - this is only possible if $n_1 > n_2$.

Snell's law can be used to find the critical angle.

Ex. Calculate the critical angle between glycerin and water.

Note that since the critical angle always produces an angle of refraction of 90°, we can clean up Snell's law for this situation:

$$\sin\theta_c = \frac{n_2}{n_1}$$

Note: $n_1 > n_2$

At the critical angle, the refracted ray will travel parallel to the interface. The greater the difference is between the indices of refraction, the smaller the critical angle.

For example, the critical angle between diamond and air is smaller than the critical angle between diamond and water.

A good idea when doing problems where $n_1 > n_2$ is to find the critical angle for the two substances. Then, if your incident angle is greater than the critical angle you will get total internal reflection.

Ex. What is the angle of refraction if the incident angle of a light beam strikes the following interfaces at 35.0°. If it reflects, what is the angle of reflection?

a) zircon - air

b) beryllium glass - ice

A practical use of total internal reflection is fiber optics.

Light Me Up

The science of measuring properties of light is called **photometry**.

We all know that the brightness of light depends on two things: the amount of light produced from the light, and the distance the observer is from the light. The rate at which visible light is emitted from a source, or the power output, is called the **luminous flux (P).** The unit of luminous flux is the **lumen (lm)**.

Most lights we will deal with will be of the incandescent variety. These light bulbs emit light in all directions. Therefore, we could imagine a sphere made of light, with our light bulb at the center of the sphere.

A standard 100 W incandescent light bulb will emit 1750 lm, meaning that if the light were at the center of a sphere then 1750 lm indicates all of the light that strikes the inside surface of the sphere during a given time period.

We are usually more concerned with the amount of light that falls on a particular area, like a book or a desk. The amount of light that falls on a given area is called **illuminance (E)**. The unit of illuminance is lm/m^2. However, physicists call 1 lm/m^2 a **lux (lx)**.

$$E = \frac{P}{4\pi r^2}$$

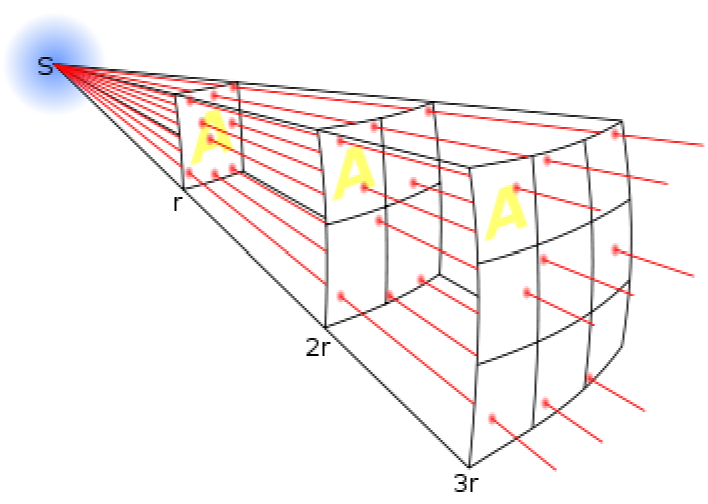
Where:

E = illuminance (lm/m^2)
P = luminous flux (lm)
r = distance object is from light (m)

Ex. What is the illuminance of a desk sitting 2.50 m below a 1750 lm incandescent light bulb?

Ex. How far away is a light source if an object has an illumination of 90.0 lx under a light producing 1500 lm?

As a surface gets farther and farther from a light source, it becomes less illuminated. In fact, the illuminance of a surface varies inversely with the square of the distance from the light source.



$$E \propto \frac{1}{d^2}$$

So, if you double the distance from a light source, then the illuminance is cut down to ¼. If you triple the distance, then the surface has only 1/9 the illuminance.

To compare two light sources, we can use this inverse-square relationship. First, find out how many times farther one object is from the source compared to the other. Then, use the inverse square relationship.

Ex. How much more illuminance does object A have sitting 3.00 m from a 1750 lm source than object B sitting 12.0 m from the source? After, compare object B to A.

Ex. What is the comparison if we changed the light bulb from 1750 lm to 2500 lm?

So, to summarize, if you wanted to increase the illumination of an object you could increase the output of the light source, or decrease the distance between the light and the object.

Intensity

The **intensity** of a light source is the luminous flux that falls on a square meter of a sphere with a radius of 1m. In other words, intensity is a measure of the **brightness** of the bulb. So, if you had an intense light bulb, it would be very bright 1 m away from it when you compare to a dim bulb from the same distance.

The unit for intensity is the **candela (cd)**. This is derived from the old unit for intensity - candle power.

Since our radius of the 'light sphere' emitted by the bulb is 1 m, then we get the following equation for intensity:

$$I = \frac{P}{4\pi}$$

Ex. What is the luminous intensity of a bulb with 1750 lm?

Ex. What is the luminous flux of a 1.5 cd light bulb?

Another equation that involves intensity is:

$$E = \frac{I}{d^2}$$

Where:
E= illuminance (lx)
I = intensity (cd)
d = distance from source (m)

Ex. What is the illumination of an object sitting 2.00 m from a bulb with an intensity of 2.75 cd?

There are two trickier situations we can introduce now. The first is when we have two objects at different distances from the **same** light bulb. The key for this situation is to notice that the light bulb will have the same **intensity** since the properties of the bulb do not change.

Mathematically, we get:

$$E_1 d_1^2 = E_2 d_2^2$$

Ex. A screen 5.00 cm away from a bulb has an illumination of 30.0 lx. Another screen is 8.50 cm away from the same bulb. What is the illumination on the second screen?

The other situation is when we have different light sources providing the same **illumination** on an object. Each light source will have its own intensity, so mathematically:

$$\frac{I_1}{d_1^2} = \frac{I_2}{d_2^2}$$

Ex. Bulb A, with a luminous intensity of 40.0 cd has the same illuminance on a screen 3.0 m away as bulb B does on a screen 1.2 m away. What is the luminous intensity of bulb B?

Unit V: Optics

Converging Lenses

A lens is a transparent optical device with a curved surface. Therefore, it can be thought of as a transparent device made up of a very large number of flat surfaces put together at slightly different angles.

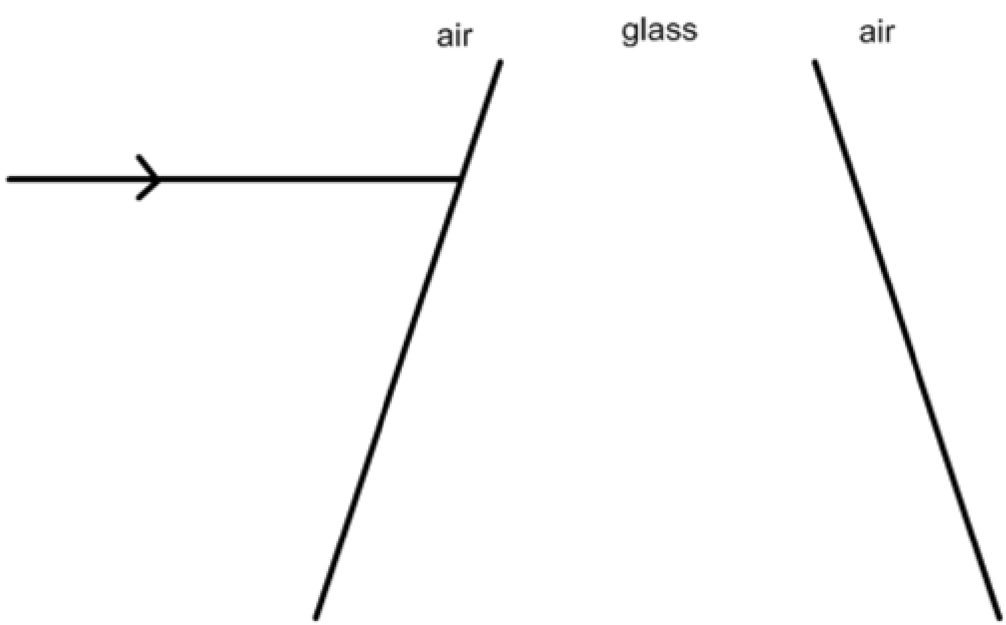
A **converging lens** is thicker at the middle than at its ends. These are also known as **convex** lenses.

We have a similar set up with lenses and mirrors.

- The **optical center** of the lens is denoted as '**o**'.
- The **principle axis** is an imaginary line perpendicular to the surface of the lens that travels through the optical center.
- The **principle focus (F)** is the point that rays parallel to the principle axis appear to converge through for a converging lens. For a converging lens, this will always be on the opposite side the light is originating on.
- The **secondary focus (F')** is a focal point on the opposite side of the principle focus. For a converging lens, this will always be on the same side that the light is originating on.
- Both the focal points are the same distance away from 'o'. This distance is known as the **focal length (f)**.

When light hits a lens, it will get refracted twice, once at each boundary. Again, we can think of each lens with many flat sides.

Ex. Show how light acts in the lens below at the microscopic scale. Then, draw a macro scale of the same behavior.



Macro Scale:

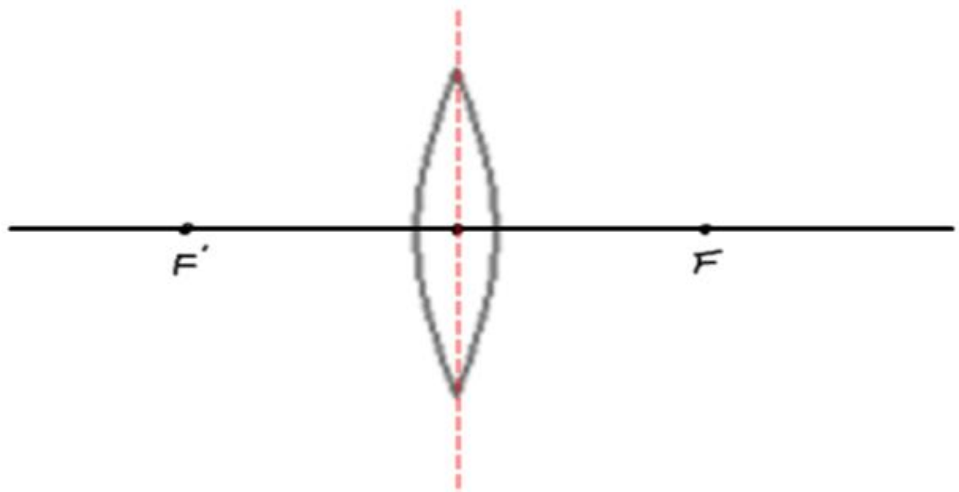
To simplify this process we will only represent the macro-scale diagrams.

That is, we will always show the refraction in the middle of our lenses on our ray diagrams at a line that is perpendicular to the principle axis that passes through ‘o’. We call this the **construction line**.

We will be drawing ray diagrams to find images in lenses.

The principle rays for converging lenses are as follows:

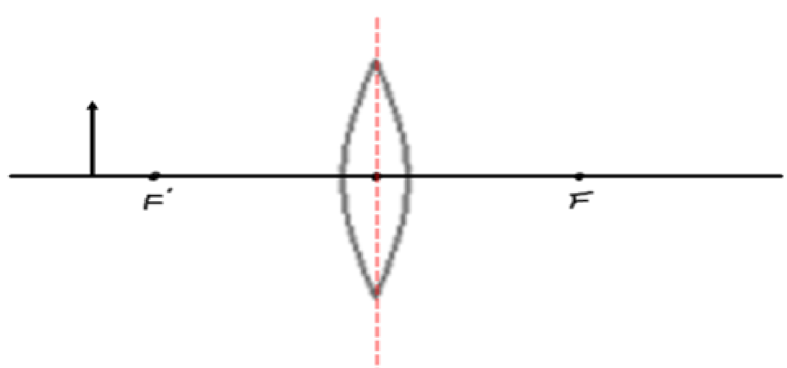
1) A ray traveling parallel to the principle axis will refract through the principle focus.
2) A ray travelling through the **secondary focus** will refract parallel to the principle axis.
3) A ray travelling through ‘o’ will continue on its path.



To locate an image, just as we did in mirrors, we need to find the intersection of two **refracted rays**.

With lenses, a **real image** appears on the opposite side the light originated on. A **virtual image** appears on the same side the light originated on. To find virtual images, you may need to extend refracted rays backwards as we did with reflected rays in mirrors.

Ex. Find the image of the object in the converging lens below and describe the characteristics:



Diverging Lenses

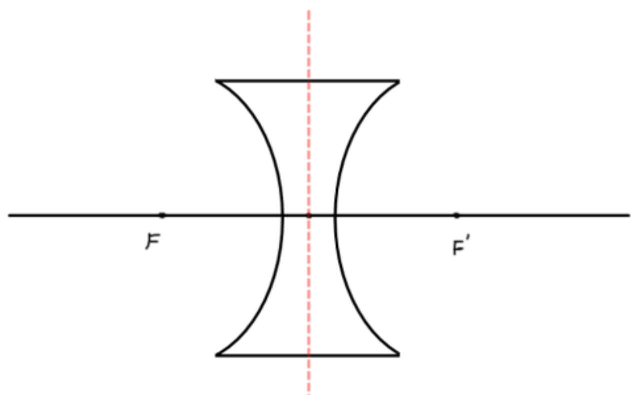
A **diverging lens** is a lens that is thinner in the middle than it is on its ends.

A diverging lens has the same basic set up as a converging lens. However, the principle focus is on the same side that light is originating on.

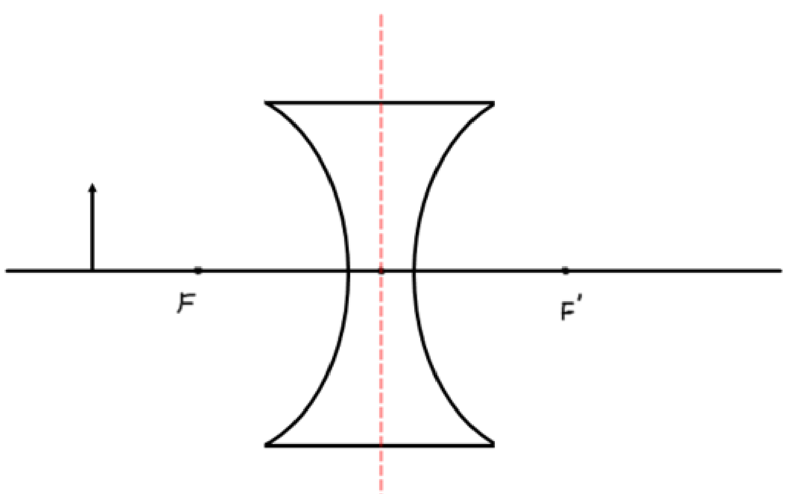
Instead of the principle focus being a point at which light converges to, it is the place where light appears to diverge from. Therefore, since light is not actually passing through this point, we think of the point as **virtual**.

The principle rays for a diverging lens are as follows:

1) A ray that travels parallel to the principle axis appears to refract from the **principle** focus.
2) A ray that travels towards the **secondary focus** will refract parallel to the principle axis.
3) A ray that travels through 'o' will continue on its path.



Ex. Locate the image of the object below:



Scale Diagrams with Lenses

Drawing scale diagrams with lenses is very similar to that we did with mirrors.

Recall that for each diagram we drew, we always stated the scale in the top left corner. The key to drawing these diagrams is to make sure you are drawing the correct lens. That is, pay close attention to whether it is **converging** or **diverging**.

Ex. An object 8.0 cm high is placed 80 cm in front of a converging lens. If the focal length of the lens is 25 cm, what is the image distance and height?

Ex. A light 10.0 cm high is placed 60.0 cm in front of a diverging lens that has a focal length of 20.0 cm. What is the image height and image distance?

Math with Lenses

Although drawing ray diagrams give us the solution to lens problems, they can be inaccurate because of measuring errors. Therefore, to get a more precise solution, we can use the following formulas:

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$M = \frac{h_i}{h_o}$$

$$M = -\frac{d_i}{d_o}$$

$$\frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Where:
- f = focal length
- d_i = image distance
- d_o = object distance
- h_i = image height
- h_o = object height
- M = magnification

The sign conventions for lenses are as follows:

	Positive	Negative
d_o		
d_i		
h_o		
h_i		
f		
M		

Ex. An object 8.0 cm high is placed 80 cm in front of a converging lens. If the focal length of the lens is 25 cm:
a) What is the image distance?

b) What is the height of the image?

Ex. A light 10.0 cm high is placed 60.0 cm in front of a diverging lens that has a focal length of 20.0 cm. What is the image height and image distance?

Just Eyeball It

How does your eye "see"?

1.) Light reflects off an object to your eye.
2.) Light refracts through the cornea.
3.) Light travels through the pupil.
4.) Light is refracted through the lens and forms an inverted real image on the retina.
5.) The retina sends messages to the brain via the optic nerve.
6.) The optical center of your brain creates the image that you "see".

Vision Defects

Myopia

- nearsightedness
- corrected using diverging, concave lens
- the distance between the lens and retina is too large causing the image to focus in front of the retina.

Hypermetropia

- farsightedness
- corrected using converging, convex lens
- the distance between the lens and the retina is too small causing the image to form "behind" the retina.

Astigmatism

- This happens when the lens of the eye has more than one focal point because the lens is rippled instead of smooth
- astigmatic people cannot see in fine detail
- corrected using cylindrical lenses

Unit VI: Heat

Kinetic Molecular Theory and Heat

Thermodynamics - the study of heat

We will use the **kinetic molecular theory** to describe **thermal energy, heat, and temperature.**

Kinetic Molecular Theory - a theory that describes matter based on the assumption that all matter is made up of tiny particles constantly in motion.

Important postulates of the kinetic molecular theory:

- All matter consists of atoms.
- Atoms may join together to form molecules.
- Molecular motion is random.
- Molecules in motion possess kinetic energy.
- Molecular motion is greatest in gases, less in liquids, and least in solids.
- Collisions between atoms and molecules transfers energy between them.

Basically, the more kinetic energy the particles have in an object the hotter the object is.

Particles are held together by electromagnetic forces. As particles vibrate and move, they gain kinetic energy (energy because of motion). The vibrations put stress on the electromagnetic forces (like springs being compressed) giving the particles potential energy (stored energy) as well.

Thermal Energy - the total energy (kinetic and potential) possessed by the particles moving in an object.

Heat - the thermal energy **transferred** from one object to another. This transfer is caused by differences in temperature between the objects.

Heat is energy, and it is measured in Joules (J).

Heat can **only** be transferred from a hot body to a cooler body, not vice versa.

Heat is denoted by 'Q'.

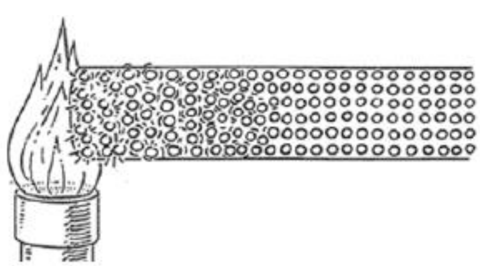
Heat = Change in Energy

Or, $Q = \Delta E$

Thermal energy can be transferred by **conduction, convection, or radiation.**

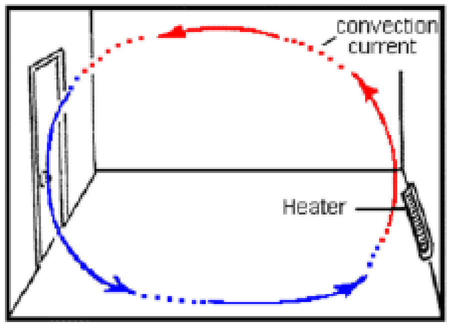
Conduction - energy is passed onto particles by bumping into each other. Fast moving particles bump into slower moving particles, transferring energy, and making them move faster.

Ex. this is how thermometers work



Convection - when a given substance is heated, the particles rise because the substance is less dense. These rising particles create a current which forces cooler particles to circulate down. The cooler particles begin to heat up as they drop and then begin to rise, starting the cycle over again.

Ex. our atmosphere



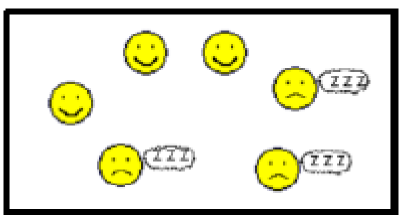
Radiation - the transfer of heat through electromagnetic waves (light, infrared, ultraviolet, microwaves, radiowaves), not matter.

Ex. the sun warming the earth

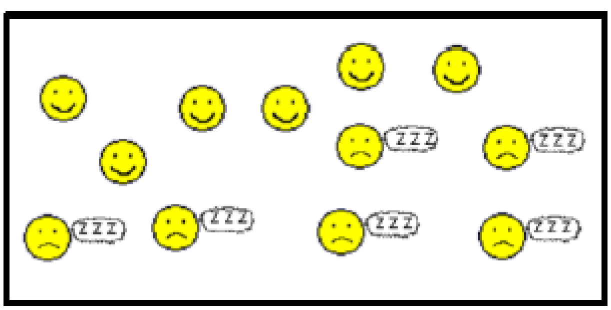
Temperature - the 'hotness' of an object measured on a specific scale (Celsius, Kelvin, or Fahrenheit). It is the **average** energy of the particles in a substance.

Temperature vs. Thermal Energy:

Substance 1:



Substance 2:



A substance containing many 'cooler' particles may have more thermal energy than a substance containing a small amount of 'hot' particles.

Ex. A cup of coffee may be 'hotter' than a swimming pool, but the swimming pool will have more thermal energy.

Thermal equilibrium - two objects become the same temperature.

Ex. a thermometer under your tongue feels cold to begin with but soon becomes the same temperature as your tongue.

Temperature Scales and Thermal Expansion

Temperature Scales

Thermometers are limited to the physical properties of the substances inside of them.

For example, an alcohol thermometer would be useless above the boiling point of alcohol. A mercury thermometer will be useless below the freezing point of mercury.

Celsius - this is calibrated to the physical properties of water.

Anders Celsius called the freezing/melting point of water 0° C, and he then called the boiling point of water 100° C. He put 100 notches between 0 and 100 and called each notch a degree.

Kelvin - based on energy. Technically, if there is no energy in an object, it will be at the coldest possible temperature. We call this **absolute zero**. At this point, there is no energy left in particles and they cease to move.

Absolute zero was set at 0 K (or -273° C). Note that the Kelvin scale does not use the ° symbol. So, on the Kelvin scale the freezing/melting point of water is 273 K and the boiling/condensing point is 373 K.

To convert from ° C to K:

K = ° C + 273

Ex. What temperature in Kelvin is 37° C?

Ex. What temperature in Celsius is 215 K?

Convert the following to degrees Celsius:

a) 4.00 K

b) 652 K

c) 200.0 K

Convert the following to degrees Kelvin:

a) 10.0° C

b) - 201° C

c) -325° C

Thermal Expansion

As objects heat up they expand. This is called **thermal expansion.**

Specifically, if we are dealing with a relatively straight solid object, like an iron rod, we say its length expands. This is called **Linear Expansion** (denoted ΔL).

The linear expansion of a solid depends on its initial length, change in temperature it undergoes, and the type of material it is made of.

$\Delta L = \alpha L_o \Delta T$ where: α = coefficient of linear expansion with units of ($°C^{-1}$, 1/°C, K^{-1}, 1/K)
L_o = original length
ΔT = change in temperature

The coefficient of linear expansion is different for different materials. A list of them will be provided on a formula sheet.

Ex. A copper rod is 2.60 m long and initially at 21°C. The bar is heated uniformly to a temperature of 93°C.
a) What is the change in length of the bar?

b) What is the final length of the bar?

Thermometers that contain liquids are calibrated by considering the amount of **volumetric expansion** that occurs within a given substance as its temperature changes. If we know this, we can determine the amount of spaces needed between each notch on the thermometer.

Volumetric expansion (ΔV) can be found with:

$\Delta V = \beta V_o \Delta T$ where: β = coefficient of volumetric expansion with units of ($°C^{-1}$, 1/°C, K^{-1}, 1/K)
V_o = original volume
ΔT = change in temperature

The coefficient of volumetric expansion will also differ depending on the material used. This value is also given on our formula sheet.

Ex. The liquid in a thermometer decreases from 120 mL to 119.6 mL when its temperature drops from 28.5°C to 10.0°C. What is the substance in the thermometer?

Specific Heat Capacity

Specific Heat Capacity is the quantity of heat required to raise the temperature of 1 kg of a substance by one degree celcius or Kelvin. It is denoted as 'c'. Specific heat capacity depends on the phase and molecular structure of the substance, therefore each substance has a unique specific heat capacity.

We can use the specific heat to determine how much heat is absorbed or released by a substance as it experiences a temperature change.

$Q = mc\Delta T$ where m = mass (kg)
c = specific heat in J/(kg°C)
ΔT = Change in temperature
Q = heat gained or lost

If Q turns out **positive** then the substance absorbed energy, and if Q is **negative** then the substance lost energy.

Ex. A 0.400 kg block of iron is heated from 295 K to 325 K. How much heat is absorbed by the iron?

Ex. 3.5 kg of an unknown substance loses 7.98 kJ of heat when its temperature drops from 25.0°C to -35.0°C. What is the specific heat?

Mixture Problems

We can heat something up by using an obvious source like a flame. We can also cool something down using an obvious source like a fridge.

However, if we had a container of water we could heat it up by dropping a mass of hot iron into it. The hot, fast moving particles in the iron will collide with the slow moving particles in the water. The energy transferred from the collisions will speed up the water particles, and slow down the iron particles.

In a system like this, we say that no energy is able to escape, but can only be transferred between the two substances. Therefore, the heat (energy) lost from the iron is gained by the water, resulting in the temperature increase of the water and temperature decrease in the steel.

The resulting mixture of substances will eventually reach the same final temperature and they will be in thermal equilibrium.

We call these problems **mixture problems.**

We will be able to recognize these problems because two substances will be involved.

Ex. A 565 g cube of gold at 255 °C is cooled by dunking it in a 1.35 kg container of water at 20.0 °C. What is the final temperature of the mixture?

Ex. A 2.00 kg mass of copper at 350 °C is covered in a mass of sand initially at 5.00 °C. If the final temperature of the system is 155.0 °C what is the mass of the sand?

Latent Heat

Latent Heat - the quantity of heat energy required to change the state of 1 kg of a given substance.

Ex. It takes 205 kJ of heat to liquefy 1 kg of solid copper at its melting point.

The units for latent heat are kJ/kg.

When a substance is undergoing a change in state its temperature does not change until **all** of it has changed state.
Ex. When melting ice, the ice stays at 0°C until it is all melted. Ice cannot exist at a temperature above 0°C.

Latent Heat of Fusion is the amount of heat energy released or absorbed in order to solidify or melt a substance, respectively.

$Q_f = mH_f$	where m = mass in kg H_f = latent heat of fusion in kJ/kg. Q_f = energy transferred

Latent Heat of Vaporization is the amount of heat energy released or absorbed in order to condense or vaporize a substance, respectively.

$Q_v = mH_v$	where m = mass in kg H_v = latent heat of vaporization in kJ/kg. Q_v = energy transferred

Hint 1 - There is **no** temperature change for latent heat problems since latent heat refers **only** to substances changing states. This fact should be used to determine if you need to use $Q = mc\Delta T$ and $Q = mH_f$ or mH_v.

Hint 2 - If a substance is being condensed, or frozen, it is releasing energy, making the H_f and H_v values negative.
Ex. How much energy is absorbed in order for 5.50 kg of iron to liquefy if it is at its melting temperature?

Ex. If 3.22×10^6 J are released when 2.3 kg of a gaseous substance is condensed, what is the substance?

The trickiest latent heat problems will involve substances that are **not** at a melting/freezing or vaporizing/condensing temperature.

What we need to continuously ask ourselves is: Are we changing **temperature** or are we changing **state**?
To help yourself out, you may want to draw a temperature vs. time graph like in the example below.

Ex) 2.30 kg of ice at -15.0°C is warmed until it evaporates into steam at 135.0°C. Sketch a temperature vs. time graph of this process. What is the total amount of heat required for this to occur?